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RESEARCH PAPER

Organic matter contribution to soil fertility improvement and maintenance in red Alder (*Alnus rubra*) silvopastoral systems

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Abstract: An investigation was conducted to quantify fine roots and roots nodules over the four seasons in forestry and agroforestry alder (*Alnus rubra*) stands in North Wales. Soil samples collected in each season were excavated at three sampling points (0.30 m, 0.57 m and 1.00 m distance from the base of each tree) from nine trees of the agroforestry and forestry plots. Result showed that the density of live fine root had significant differences in between seasons and treatments (P < 0.001). The mean weight density of live fine root over the four seasons in agroforestry and forestry was 0.27±0.01 kg·m^{-3} and 0.54±0.03 kg·m^{-3}, respectively. Weight density of dead root in each system remained constant throughout the year. The mean weight density of dead root was also significantly different (P < 0.01) between forestry and agroforestry systems. Weight density of live and dead root nodule was both constant throughout the year and between the different sampling distances. The mean weight densities of live and dead root nodule over the four seasons were 0.09±0.03 kg·m^{-3} and 0.05±0.03 kg·m^{-3} in agroforestry and 0.08±0.02 kg·m^{-3} and 0.03±0.01 kg·m^{-3} in the forestry plots, respectively.

Keywords: alder; *Alnus rubra*; root nodule; fine root; nitrogen

Introduction

Several reports demonstrated the attractive role of nitrogen-fixing trees as sources of nitrogen and organic matter and their potential in soil fertility improvement and maintenance (Giller 2003; Scroth and Sinclair 2003; Teklehaimanot and Martin 1999; Young 1997). Red alder (*Alnus rubra*) is one of the important nitrogen-fixing tree species in temperate and boreal ecosystems (Binkley et al. 1994; Rojas et al. 2002). Red alder has been planted in mixture with non-nitrogen-fixing trees to provide the nitrogen in forest plantation in USA (Binkley et al. 1994). Experiments were conducted with the tree on pasture in North Wales, UK for the same reason (Teklehaimanot and Martin 1999). The incorporation of this tree species in agroforestry system is cheaper with reduced pollution to the environment compared with the use of commercial fertilizers (Teklehaimanot and Martin 1999).

Nitrogen-fixing trees provide organic matter to soil through decay of fine roots, nodules and leaf litter. Previous study suggested that fine root turnover of the tree species made great contribution to the recycling of nutrients and carbon in the rhizosphere and consequently promoted soil nutrient balance (Lehmann and Zech 1998; Curt et al. 2001; Makkonen et al. 1999; Nygren et al. 1995; Ruess et al. 1996; Tufekcioglu et al. 1999). In addition, tree physiological activities of the species such as death or decomposition of the fine roots and root nodules also contributed to the net balance of carbon and nitrogen in the soil. However, studies on nodule weight density in red alder and indeed in other nitrogen-fixing plants were not given the deserved attention. Only a few articles published involved in the effects of different pruning regimes of other trees species on nodule distribution and dynamics in agroforestry systems (Chisney et al. 2002; Nygren et al. 1995). The present study is to estimate the contribution of red alder to soil organic matter and nitrogen content in a silvopastoral system.

Materials and methods

Experimental site description

The experiment was conducted at the experimental site of a 10-year-old red alder silvopastoral system at the University of Wales, Hanfaes farm. Red alder trees were planted at a density of 400 stem·ha^{-1} for agroforestry and at 2500 stem·ha^{-1}for forestry. The Hanfaes research centre is located in Abergwyngregyn, Gwynedd, 12 km far from east of Bangor. The climate is Hyperoceanic with the annual rainfall of about 1000 mm. The soil is mainly a fine loamy brown earth over gravel classified as Rheidol series (UN- Dystric Cambisol). There is a shallow slope of about 1–2° on the deltaic fan, with a northwest aspect at an altitude ranging from 4 m to 14 m above sea level. The water table

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of the area is 1 m to 6 m depth (Teklehaimanot and Martin 1999).

Roots and nodule sampling

Belowground biomass of fine roots and nodules was estimated using a modified quarter spiral trench technique (Fig. 1), as described by Tomlinson et al. (1998). In this study, core samples were taken instead of trench sampling, as the shallow brown earth with gravel was difficult to dig. Spiral sampling enabled a large proportion of the soil cores to be excavated with only minimal damage to the tree. Soil cores of 30 cm × 20 cm × 15 cm were excavated at three sampling points (0.30 m, 0.57 m and 1.00 m distance from the base of each tree) from nine trees of the agroforestry and forestry plots. Core samples were collected in each season to obtain an average for a year. A total of 54 core samples were collected during each season to estimate the average amounts of roots and root nodules in the agroforestry and forestry systems. Again trees in the border were not selected to avoid edge effects. The core samples were labelled and stored in a cold store for approximately one week before being separated into roots, nodules and soil in the greenhouse of the University of Wales Bangor, UK.

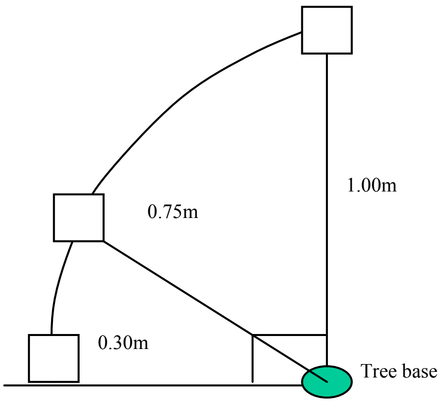

Fig. 1 Diagram showing sampling points (at 0.30 m, 0.75 m and 1.00 m) from tree base using logarithmic spiral technique

Wet sieving was used for the separation of roots and nodules from the soil. The fabric suspension bucket hanging funnels with connected hush links beneath was used to separate the roots and nodules from the soil. A centrally powered valve water circulation system allowed the roots and nodules to float from the bucket into the hanging funnels. All grass roots and large roots (tree roots more than 2 mm in diameter) were discarded. Red alder roots were distinguished from grass roots by the difference in colour. The fine roots and nodules were further separated into categories of the live and the dead. All the samples were oven dried at 80°C for two days in a laboratory and then weighed and their weight density was recorded. The biomass of leaves, fine roots and dead nodules and their nitrogen contents were used to estimate the potential contribution by red alder to the organic matter and nitrogen content of the soil. Nitrogen content was analysed using the Kjeldahl method (AOAC 1995).

Statistical analysis

Fine roots and root nodules were sampled on samples collected from agroforestry and forestry systems. Means of fine roots and root nodules in forestry and agroforestry systems were compared using analysis of variance (ANOVA), generalised linear modelling in Minitab 13 statistical software package. Standard errors of the means were used to separate the means.

Results

Live and dead root weight density and biomass

The live root weight density showed a significant difference between agroforestry and forestry plots (P < 0.001) (Table 1). Mean live root weight density over the four seasons in agroforestry and forestry was 0.27±0.01 kg·m^{-3} and 0.54±0.03 kg·m^{-3}, respectively. An analysis on the mean root density suggested that seasonality had no effect on the live root weight density in the forestry plots.

Table 1. Live root weight density (kg·m^{-3} ± SE) of red alder over the four seasons, soil cores were excavated at three sampling points (0.30, 0.57 and 1.00 metres distance from the base of each tree)

	Distance (m)	Winter	Spring	Autumn	Summer	Mean
Agroforestry	0.30	0.11±0.01	0.23±0.07	0.34±0.06	0.47±0.06	
	0.57	0.20±0.04	0.21±0.06	0.26±0.04	0.41±0.04	
	1.00	0.21±0.05	0.18±0.03	0.30±0.04	0.40±0.10	
	Mean	0.17±0.02	0.21±0.03	0.30±0.03	0.43±0.04	0.27±0.01
Forestry	0.30	0.42±0.07	0.52±0.13	0.46±0.09	0.46±0.06	
	0.57	0.44±0.13	0.40±0.08	0.54±0.10	0.65±0.09	
	1.00	0.69±0.18	0.66±0.12	0.63±0.16	0.62±0.10	
	Mean	0.52±0.02	0.53±0.07	0.54±0.07	0.58±0.05	0.54±0.03

Significant difference (P < 0.01) in the root weight density existed between the two systems (Table 2). Mean dead root weight density in forestry and agroforestry was 0.08±0.01 kg·m^{-3} and 0.04±0.01 kg·m^{-3}, respectively. The mean dead root weight density remained constant throughout the four seasons in both agroforestry and forestry plots.

Live and dead nodule weight density and biomass

Mean live and dead nodule weight densities were not different between the different seasons (P > 0.001) according to the dynamics as shown in Figs. 2 and 3. Mean live and dead nodule weight densities over the four seasons were 0.09±0.03 kg·m^{-3} and 0.05±0.03 kg·m^{-3} in the agroforestry plots and 0.08±0.02 kg·m^{-3} and 0.03±0.01 kg·m^{-3} in the forestry plots, respectively. Moreover, nodule weight density in agroforestry was not significantly different (P < 0.01) from the density in forestry plots.

Contribution of red alder to soil organic matter and nitrogen content

Table 3 showed the amount of fine root and dead root nodule contributing to soil organic matter and nitrogen in agroforestry and forestry systems. Senescent leaves, fine roots and dead nodules were assumed to pass to soil organic matter through decomposition. The total amount of organic matter added to the soil through senescent leaves and fine roots and dead nodules was estimated at 0.4 kg·m^{-3}·a^{-1} in agroforestry and 0.9 kg·m^{-3}·a^{-1} in forestry. The total amount of nitrogen that could potentially be added to the soil as a result of decomposition of senescent leaves, root and dead nodules was estimated at 0.004 kg·m^{-3}·a^{-1} and 0.01 kg·m^{-3}·a^{-1} in agroforestry and forestry, respectively (Table 3).

Table 2. Dead root weight density (kg·m^{-3} ± SE) of red alder over the four seasons, soil cores were excavated at three sampling points (0.30, 0.57 and 1.00 metres distance from the base of each tree)

	Distance (m)	Winter	Spring	Autumn	Summer	Mean
Agroforestry	0.30	0.049±0.02	0.016±0.01	0.039±0.01	0.024±0.01	
	0.57	0.021±0.01	0.029±0.01	0.040±0.01	0.039±0.01	
	1.00	0.045±0.01	0.047±0.03	0.045±0.01	0.041±0.01	
	Mean	0.038±0.01	0.030±0.01	0.041±0.01	0.035±0.01	0.036±0.01
Forestry	0.30	0.079±0.02	0.064±0.01	0.064±0.01	0.117±0.02	
	0.57	0.102±0.03	0.033±0.01	0.061±0.02	0.078±0.01	
	1.00	0.074±0.02	0.092±0.03	0.110±0.02	0.076±0.01	
	Mean	0.085±0.01	0.063±0.01	0.078±0.01	0.090±0.01	0.079±0.01

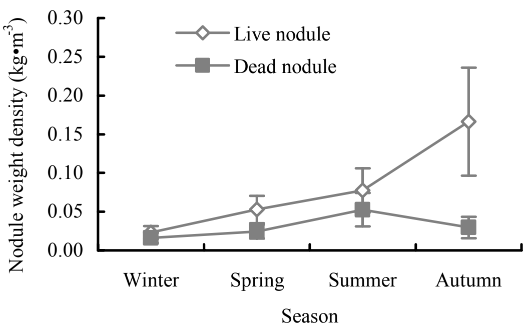

Fig. 2 Live and dead nodule weight density (kg·m^{-3} ± SE) at different seasons in red alder forestry plots.

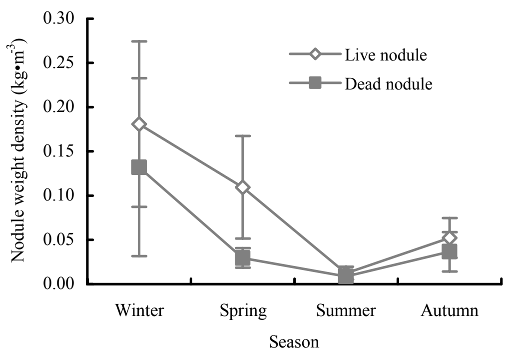

Fig. 3 Live and dead nodule weight density (kg·m^{-3} ± SE) at different seasons in red alder agroforestry plots

Table 3. Organic matter (kg·m^{-3}·a^{-1}) and nitrogen (kg·m^{-3}·a^{-1}) addition to the soil in red alder agroforestry and Forestry

Systems	Addition to the soil	Leaves	Fine roots	Dead root nodules	Total
Agroforestry	Organic matter addition	0.04	0.31	0.05	0.40
	Total Nitrogen addition	1.0x10^{-3}	2.1x10^{-3}	9.6x10^{-4}	4.1x10^{-3}
Forestry	Organic matter addition	0.27	0.62	0.03	0.92
	Total Nitrogen addition	6.3x10^{-3}	4.2x10^{-3}	5.7x10^{-4}	1.1x10^{-3}

Discussion

In the present study, fine root weight density was observed to be higher in the autumn and summer seasons than in the winter and spring in both the agroforestry and forestry plots. The high values of root weight density may be attributed to the high moisture content and optimal temperatures in growing seasons. This finding agrees with results of Makkonen and Helmissaari (1999). Baddeley and Watson (2004) studied seasonal patterns in fine root production and mortality in Scotland and reported the highest occurrence of roots and net production occurred in the summer period.

There was a significant difference in both live and dead root weight densities in forestry and agroforestry plots. The forestry plots yielded the highest root counts. This may be due to higher tree planting density in forestry, increasing the root overlap among adjacent trees. Red alder grown alone as in forestry has been reported to have shallow, fibrous and laterally wide spreading root system (Binkley et al. 1985). The reduced root weight density in agroforestry may also be due to the effect of soil compaction by grazing sheep and competition with roots of pasture (Bezkorowanjnyj et al. 1993). Sheep grazing in the area may result in compact soils, increased bulk density of the soil and reduced soil penetration by fine roots (Bezkorowanjnyj et al. 1993). However, the presence of ryegrass in agroforestry, which has a dense, shallow and fibrous root system may compete and

affect the fine root weight density of red alder.

There was no significant difference in either live or dead nodule weight density between agroforestry and forestry plots, seasons and distances from tree base. Mean live and dead nodule weight densities over the four seasons were 0.09±0.03 kg·m^{-3} and 0.05±0.03 kg·m^{-3} in the agroforestry plots and 0.08±0.02 kg·m^{-3} and 0.03±0.01 kg·m^{-3} in the forestry plots, respectively. Studies by Chesney and Nygren (2002) on *Erythrina poeppigiana* reported lower root nodule addition to the soil ranging between 0.006 kg·m^{-3} and 0.02 kg·m^{-3} nodules after pruning.

According to the results of the present study, senescent leaves, fine roots and dead root nodules could potentially contribute organic matter by 0.4 kg·m^{-3}·a^{-1} to the soil in agroforestry and 0.9 kg·m^{-3}·a^{-1} in the forestry systems. Comparable quantities of organic matter addition to the soil in the form of annual prunings have been reported at 0.45 kg·m^{-3}·a^{-1} (Seiter et al. 1999). The study showed that significantly large quantities of dead fine roots and root nodules were found in soils within the agroforestry and forestry treatments. These contribute significantly to soil organic matter and nitrogen content of the soil.

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